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1. Your reference — ACH/HMC/63467/000

0317839.9

2. Patent application number *(The Patent Office will fill in this part)* — 30 JUL 2003

31JUL03 E826577-6 D02882
~~P01/7700 0.00-0317839.9~~

3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

UNIVERSITY OF SURREY
GUILDFORD
SURREY
GU2 7XH

Patents ADP number *(if you know it)* — 7985 12002

If the applicant is a corporate body, give the country/state of its incorporation

4. Title of the invention — SOLVENT REMOVAL PROCESS

5. Name of your agent *(if you have one)* — BOULT WADE TENNANT

"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

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Patents ADP number *(if you know it)* — 42001

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Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

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Number of earlier application	Date of filing *(day / month / year)*

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Claim (s)	3 DL
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Request for preliminary examination and search *(Patents Form 9/77)*	1
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11. I/We request the grant of a patent on the basis of this application.

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Solvent Removal Process

The present invention relates to a process for removing a solvent from a solution. In particular, although not exclusively, the present invention relates to a process for removing water from an aqueous solution, such as seawater.

Various methods for removing solvents from solutions are known. For example, water may be separated from seawater by conventional desalination techniques, such as reverse osmosis. In reverse osmosis, seawater is placed on one side of a semi-permeable membrane and subjected to pressures of 5 to 8 MPa. The other side of the membrane is maintained at atmospheric pressure. The resulting pressure differential causes water to flow across the membrane, leaving a salty concentrate on the pressurized side of the membrane.

After a period of operation, the pores of the semi-permeable membrane may become obstructed by deposited salts, biological contaminants and suspended particles in the seawater. Thus, higher pressures may be required to maintain the desired level of flow across the membrane. The increased pressure differential may encourage further clogging to occur. Thus, the membranes must be cleaned and replaced at regular intervals, interrupting the continuity of the process.

Attempts have been made to reduce the level of clogging of the membrane. For example, the seawater may be pretreated to remove suspended particles and biological matter. Alternatively or additionally, the residual solution on the

high-pressure side of the membrane may be discharged at regular intervals to prevent the osmotic pressure from exceeding a predetermined threshold.

According to the present invention, there is provided a process for removing a solvent from a first solution, said process comprising

positioning a semi-permeable membrane between the first solution and a second solution having a higher solute concentration than the first solution, such that solvent from the first solution passes across the membrane to dilute the second solution, and

extracting solvent from the second solution.

The solute of the first solution may be the same as or different to the solute of the second solution. One or more solutes may be present in each of the solutions. In a preferred embodiment, the first solution comprises a plurality of solutes, whilst the second solution comprises a single solute.

In the process of the present invention, the first solution is placed on one side of a semi-permeable membrane. A second solution having a higher solute concentration (and, therefore, a lower solvent concentration) is placed on the opposite side of the membrane. As a result, solvent passes across the membrane from the side of low solute concentration (high solvent concentration) to the side of high solute concentration (low solvent concentration). The flow occurs along a concentration gradient. Thus, high pressures are not required to induce solvent flow. However,

a pressure differential across the membrane may be applied, for example, to enhance the speed of the separation process.

As solvent passes from the first solution into the second solution, the first solution becomes increasingly concentrated. Once the concentration of the first solution reaches a certain threshold, the solution may be recovered or discarded. Thus, the process of the present invention may be used to convert the first solution into a concentrated form for disposal. Alternatively, further solvent may be removed from the concentrated first solution by placing this solution on one side of a semi-permeable membrane. A further solution having a solute concentration that is higher than that of the concentrated solution may be placed on the opposite side of the membrane, such that solvent from the concentrated first solution passes across the membrane into the further solution.

After solvent from the first solution has passed into the second solution, the second solution may be recovered. The second solution may be at an elevated pressure, even when a pressure is not applied to induce solvent flow from the first solution to the second solution. This is because the flow of solvent from the first solution into the second solution occurs along a concentration gradient. This pressure may be used to aid the subsequent extraction of solvent from the second solution. For example, when solvent is extracted from the second solution by reverse osmosis, the pressure of the second solution may be used to supplement the pressure applied to the second solution to induce solvent flow from the second solution across the semi-permeable membrane.

Solvent may be extracted from the second solution using any suitable method. For example, the solvent may be extracted by distillation (e.g. thermal distillation) or using a membrane. Suitable membrane methods include reverse osmosis, electrodialysis and ion exchange. Preferably, reverse osmosis is used.

The solvent of the second solution may be the same or different to the solvent of the first solution. When the solvent of the second solution is different to the solvent of the first solution, the extracted solvent will contain a mixture of solvents from the first solution and the second solution. This may be useful, for example, when it is desired to produce a substantially pure mixture of two solvents from separate impure solutions.

Preferably, the solvent in the first solution is the same as that of the second solution. Thus, the extracted solvent consists essentially of a single solvent. The extracted solvent may be recovered and used in its recovered form, or treated further prior to use. For example, when the extracted solvent is water, the water may be stabilized, for example, by passing the water through an aeration column to adjust its pH.

When solvent is extracted from the second solution, a solid residue or residual solution generally remains behind. This residue or residual solution may be discarded. Alternatively, the solid residue may be recovered and used to make fresh second solution for extracting solvent from the first solution. As regards the residual solution, this

may be recovered and recycled, for example, for use as fresh second solution for extracting solvent from the first solution. In certain cases, it may be possible to use the residual solution directly as fresh second solution. In other cases, it may be necessary to pre-treat the residual solution, for example, by varying its concentration accordingly.

The second solution may be a solution of an organic compounds, a biological compound and/or an inorganic compound. Suitable organic compounds include hydrocarbons, such as aliphatic and aromatic hydrocarbons. Mixtures of two or more organic compounds may be employed. The hydrocarbons may be straight chain, branched and/or cyclic. Examples of suitable hydrocarbons include, but are not limited to, alkanes, alkenes and alkynes. The hydrocarbons may be substituted with one or more heteroatoms, for example, fluorine, chlorine, bromine, iodine, oxygen, sulphur, nitrogen, and/or phosphorus atoms. In one embodiment, oxygenated hydrocarbons, such as aldehydes, ketones, carboxylic acids, ethers, esters, alcohols and/or their derivatives may be employed.

Suitable biological compounds include proteins, amino acids, nucleic acids, carbohydrates and lipids. Mixtures of two or more biological compounds may be employed.

Suitable inorganic compounds include acids, bases and, preferably, salts. Mixtures of two or more inorganic compounds may be employed. Suitable acids include, but are not limited to, HCl, HBr, HI, HF, nitric acid, sulphurous

acid, sulphuric acid, carbonic acid and phosphorus acid. Mixtures of two or more acids may be employed.

Suitable bases include hydroxides, such as alkali metal hydroxides and ammonium hydroxides. Examples of suitable alkali metal hydroxides include sodium hydroxide, potassium hydroxide and lithium hydroxide. Metal oxides may also be employed. Mixtures of two or more bases may be employed.

Suitable salts include metal or ammonium salts. Mixtures of two or more salts may be employed. Examples include, but are not limited to, fluorides, chlorides, bromides, iodides, sulphates, sulphites, sulphides, carbonates, hydrogencarbonates, nitrates, nitrites, nitrides, phosphates, aluminates, borates, bromates, carbides, chlorides, perchlorates, hypochlorates, chromates, fluorosilicates, fluorosilicates, fluorosulphates, silicates, cyanides and cyanates. Preferably, salts of alkali and/or alkali earth metals are employed. Examples of such metals include, but are not limited to, lithium, sodium, potassium, magnesium, calcium and strontium. In a preferred embodiment, the second solution is an aqueous solution of sodium chloride.

The second solution may be formed of an organic and/or inorganic solvent. Suitable organic solvents include hydrocarbons, such as aliphatic and aromatic hydrocarbons. Mixtures of organic solvents may be employed. The hydrocarbons may be straight chain, branched and/or cyclic. Examples include, but are not limited to, alkanes, alkenes and alkynes. The hydrocarbons may be substituted with one or more heteroatoms, for example, fluorine, chlorine,

bromine, iodine, oxygen, sulphur, nitrogen, and/or phosphorus atoms. In one embodiment, oxygenated hydrocarbons, such as aldehydes, ketones, carboxylic acids, ethers, esters, alcohols and/or their derivatives may be employed. For example, glycol ethers and glycol ether esters may also be employed. Alternatively or additionally, halogenated solvents, such as chlorinated, brominated and/or fluorinated hydrocarbons may be employed.

Suitable inorganic solvents include acidic solvents, alkaline solvents and/or water. Suitable acidic solvents include, but are not limited to, HCl, HBr, HI, HF, nitric acid, sulphurous acid, sulphuric acid, carbonic acid and phosphorus acid. Mixtures of two or more acidic solvents may be employed.

Suitable alkaline solvents include aqueous hydroxide solutions, such as alkali metal hydroxides and ammonium hydroxides. Examples of suitable alkali metal hydroxides include sodium hydroxide, potassium hydroxide and lithium hydroxide. Mixtures of two or more alkaline solvents may be employed.

Water or an aqueous solution is preferably employed as solvent in the second solution.

Preferably, the second solution has a known composition. For example, in one embodiment, the second solution is formed by introducing a known quantity of a solute into a known quantity of solvent. Preferably, the second solution consists essentially of a selected solute dissolved in a selected solvent. By forming the second solution in this

manner, a substantially clean solution may be produced. Preferably, the second solution has a reduced concentration of suspended particles, biological matter and/or other components that may cause fouling of the apparatus used to extract solvent from the second solution. More preferably, the second solution is substantially free of such components. Thus, membrane techniques may be used to extract solvent from the second solution without fear of the pores of the membrane being subjected to unacceptably high levels of fouling, for example, by biological matter or suspended particles.

The process of the present invention may be used to purify a solvent, such as an organic or inorganic solvent. The solvent to be purified is typically present in the first solution and is, preferably, also present in the second solution. Mixtures of solvents may be purified using the process of the present invention. For example, the process may be used to purify a mixture of alcohol and water.

~~The process of the present invention may be used to purify~~ organic solvents, such as hydrocarbons (e.g. aliphatic and aromatic hydrocarbons). Such solvents are typically present in the first solution. Mixtures of organic solvents may be purified. The hydrocarbons may be straight chain, branched and/or cyclic. Examples include, but are not limited to, alkanes, alkenes and alkynes. The hydrocarbons may be substituted with one or more heteroatoms, for example, fluorine, chlorine, bromine, iodine, oxygen, sulphur, nitrogen, and/or phosphorus atoms. In one embodiment, oxygenated hydrocarbons, such as aldehydes, ketones, carboxylic acids, ethers, esters, alcohols and/or their

derivatives may be purified. For example, glycol ethers and glycol ether esters may also be employed. Alternatively or additionally, halogenated solvents, such as chlorinated, brominated and/or fluorinated hydrocarbons may be purified.

The process of the present invention may be used to purify inorganic solvents, such as acidic solvents, alkaline solvents and neutral solvents, such as water. Such solvents are preferably present in the first solution and may, additionally be present in the second solution. For example, the process of the present invention may be used to purify acidic solvents, such as HCl, HBr, HI, HF, nitric acid, sulphurous acid, sulphuric acid, carbonic acid and/or phosphorus acid. Alternatively, the process of the present invention may be used to purify alkali solvents, such as aqueous hydroxide solutions (e.g. alkali metal hydroxides and ammonium hydroxides). Examples of suitable alkali metal hydroxides include sodium hydroxide, potassium hydroxide and lithium hydroxide.

Preferably, the process of the present invention is used to purify water. The purified water stream may be used for a variety of applications, for example, for industrial, agricultural, commercial and domestic use (e.g. to produce drinking water). In one embodiment, the purified water stream may be used to pump oil from oil wells. In conventional methods, seawater is introduced into an oil well at high pressure to force the oil from the well to the surface. The use of seawater, however, causes severe fouling and scaling problems. Moreover, it can be difficult to separate seawater from oil, giving rise to separation problems once the oil is recovered. By using a purified

water stream produced by the present invention, these problems may be alleviated and/or eliminated.

The process of the present invention may be used to purify water from a waste stream, such an industrial effluent or agricultural effluent. Thus, such waste streams may be used as the first solution, or pretreated to form the first solution. The process of the present invention may also be used to purify water from other sources, for example, water from rivers or underground sources.

Preferably, the process of the present invention is used to desalinate a saline solution, such as seawater or brackish water. In this embodiment, the saline solution (e.g. seawater or brackish water) is used as the first solution and is placed on one side of semi-permeable membrane. A second solution having a higher sodium chloride concentration than the solute concentration of the saline solution is placed on the other side of the membrane. For the avoidance of doubt, it should be noted that the solute concentration of the first solution is the total dissolved salts concentration of the saline solution, and not the concentration of sodium chloride.

The difference in solute concentration on either side of the membrane causes water from the saline solution (e.g. seawater or brackish water) to pass into the second solution by osmosis. As the flow of water occurs along the concentration gradient, high pressures are not required to induce flow. However, a pressure differential across the membrane may be used, if desired.

To reduce costs, this separation step may be carried out in the absence of an applied pressure. Thus, although fouling of the membrane may occur, for example, by biological matter (e.g. seaweed, algae, bacteria, fungi and plankton) and suspended particles (e.g. dirt, soil, mud, silt, organic colloids, silica, precipitates and sand particles) in the saline solution (e.g. seawater or brackish water), the membrane may be cleaned or replaced without interrupting an expensive stage of the desalination process. Moreover, as this separation step may be carried out without pressurization, there is no need to re-pressurize the membrane when re-starting the process.

The flow of water from the saline solution dilutes the second solution. Water is then extracted from the diluted second solution. Suitable extraction techniques include distillation, reverse osmosis, electrodialysis and ion exchange. In a preferred embodiment, reverse osmosis is employed.

In reverse osmosis, the second solution may be placed on one side of a semi-permeable membrane, and subjected to a high pressure. The other side of the membrane is maintained at a lower pressure. The resulting pressure differential causes solvent (e.g. water) to flow across the membrane, leaving behind a residual solution on the pressurized side of the membrane.

The pressure differential employed in reverse osmosis may be about 0.1 to 20 MPa, preferably, about 0.5 to 15 MPa, more preferably, about 0.7 to 7 MPa, and most preferably, about 1 to 3 MPa. One side of the membrane may be pressurized,

whilst the other side may be maintained at atmospheric or a sub-atmospheric pressure. Preferably, only one side of the membrane is pressurized. The pressurized side of the membrane may be subjected to a pressure of about 0.1 to 20 MPa, preferably, about 0.5 to 15 MPa, more preferably, about 0.7 to 7 MPa, and most preferably, about 1 to 3 MPa. It should be understood that the precise pressure required would vary depending, for example, on the relative solute concentrations of the solutions on either side of the membrane.

As explained above, the second solution may contain a lower concentration of components that cause membrane fouling (e.g. biological matter and suspended particles) than the first solution. In such embodiments, the pressure required to extract solvent from the diluted second solution by reverse osmosis is generally less than the pressure required to extract solvent from the first solution by reverse osmosis. For example, pressures of 5 to 8 MPa are required to desalinate seawater directly be reverse osmosis. In contrast, a pure aqueous saline solution having the same total dissolved salts (TSD) concentration as seawater may be desalinated using significantly lower pressures, at least partly because of the lower levels of fouling encountered with the pure aqueous saline solution.

The process of the present invention may be continuous or a batch process.

Any suitable semi-permeable membrane may be used in the process of the present invention. An array of membranes may be employed. Suitable membranes include cellulose acetate

(CA) and polyamide (PA) membranes. The membrane may be planar or take the form of a tube or hollow fibre. Thin membranes may be employed, particularly, when a high pressure is not applied to induce solvent flow from the first solution to the second solution. If desired, the membrane may be supported on a supporting structure, such as a mesh support.

In one embodiment, one or more tubular membranes may be disposed within a housing or shell. The first solution may be introduced into the housing, whilst the second solution may be introduced into the tubes. As the solvent concentration of the first solution is higher than that of the second, solvent will diffuse across the membrane from the first solution into the second solution. Thus, the second solution will become increasingly diluted and the first solution, increasingly concentrated. The diluted second solution may be recovered from the interior of the tubes, whilst the concentrated first solution may be removed from the housing.

When a planar membrane is employed, the sheet may be rolled such that it defines a spiral in cross-section. When a membrane is used to extract solvent from the second solution, for example, by reverse osmosis, the type of membrane employed may be the same or different to that employed in the first separation step.

The pore size of the membrane may be selected depending on the size of the solvent molecules that require separation. It may be possible to use a membrane having a pore size that

allows two or more different types of solvent molecules to pass through the membrane.

The flow of solvent across a semi-permeable membrane is generally influenced by thermal conditions. Thus, the solutions on either side of the semi-permeable membrane may be heated or cooled, if desired. The solutions may be heated to temperatures of 30 to 300°C, for example, 40 to 80°C. Alternatively, the solutions may be cooled to -20 to 20°C, for example, 7 to 12°C. The solution on one side of the membrane may be heated, while the other side cooled. The heating or cooling may be carried out on each solution independently. Chemical reactions may also be carried out on either side of the membrane, if desired.

The process of the present invention may further comprise a pre-treatment step of removing contaminants, such as suspended particles and biological matter, from the first solution (e.g. a waste stream, seawater or brackish water). Additionally or alternatively, a threshold inhibitor to control scaling may be added to the first solution. Pre-treatment steps to alter the pH of the first solution may also be employed.

According to a further aspect of the invention, there is provided the use of a direct osmosis step in a process for the desalination of a saline solution by reverse osmosis.

The saline solution may be seawater or brackish water.

A preferred embodiment of the process of the present invention will now be described, by way of example, with reference to the accompanying drawings, in which

Figure 1 is a schematic flow diagram of an apparatus for desalinating seawater by a conventional reverse osmosis process, and

Figure 2 is a schematic flow diagram of an apparatus for desalinating seawater using a process according to an embodiment of the present invention.

Reference is first made to Figure 1 of the drawings. This Figure depicts an apparatus 10 for performing a conventional desalination process by reverse osmosis. The apparatus 10 comprises a high-pressure pump 12 and a membrane module 14. The module 14 contains a semi-permeable membrane 16.

In use, seawater is pumped into the module 14 using the high-pressure pump 12. This causes the seawater to come into contact with the one side of the semi-permeable membrane 16 at high pressure. Typically, pressures of 5 to 8 MPa are employed. As a result, water flows through the membrane 16, leaving a concentrated seawater solution on the pressurized side of the membrane 16. The concentrated seawater solution may be removed and discarded via line 18.

The water collected on the unpressurized side of the membrane 16 is substantially pure, and is removed from the module 14 via line 20.

After a period of use, the semi-permeable membrane 16 becomes clogged by deposits and suspended particles in the seawater. Thus, the reverse osmosis step has to be stopped about every two to four months to clean and/or replace the membrane 16.

Reference is now made to Figure 2 of the drawings, which depicts an apparatus for desalinating seawater using a process according to an embodiment of the present invention. The apparatus 100 comprises a first membrane module 110 and a second membrane module 112. Each of the modules 110, 112 contains a semi-permeable membrane 114a, 114b. The first membrane module 110 is coupled to a storage tank 116.. The storage tank 116 is coupled to the second membrane module 112 via a pump 118. The apparatus 100 also comprises a mixing tank 120 for producing a saline solution.

A saline solution is formed in mixing tank 120 by dissolving a known quantity of sodium chloride in water. The resulting solution has a sodium chloride concentration that is higher than the total dissolved salt (TSD) concentration of the seawater under treatment.

Seawater is introduced to one side of the membrane 114a of the first membrane module 110 via line 122. The saline solution is introduced to the other side of the membrane 114a. As the saline solution has a sodium chloride concentration that is higher than the total dissolved salt (TSD) concentration of seawater, water flows across the membrane 114a by direct osmosis. The flow of water dilutes the saline solution, leaving behind a salty residual

solution on the seawater side of the membrane 114a. The latter may be removed via line 124.

The diluted saline solution is recovered from the first membrane module 110 and transferred to the storage tank 120. The diluted saline solution is then transferred to the second membrane module 112 using the pump 118.

In the second membrane module 112, the diluted saline solution is contacted with one side of the semi-permeable membrane 114b at high pressure. As a result, water flows through the membrane 114b, leaving a concentrated residue on the pressurized side of the membrane 114b. The concentrated residue may be recycled for use as the second solution via line 126.

The water collected on the unpressurized side of the membrane is substantially pure, and is removed from the second membrane module 112 via line 128.

An advantage of the embodiment of Figure 2 is that the pressure required to operate the second membrane module 112 is lower than that required using the conventional process of Figure 1 mainly because the degree of fouling encountered with the second solution is significantly less than that encountered with the first solution. For example, pressures of 2 to 4 MPa may be employed. Moreover, as pure sodium chloride solution contains a lower concentration of suspended particles and biological matter than seawater, less blocking and fouling of the membrane 114b occurs. Thus, the membrane 114b does not need to be cleaned and/or replaced as frequently.

CLAIMS

1. A process for removing a solvent from a first solution, said process comprising

positioning a semi-permeable membrane between the first solution and a second solution having a higher solute concentration than the first solution, such that solvent from the first solution passes across the membrane to the second solution, and

extracting solvent from the second solution.

2. A process as claimed in claim 1, wherein the solute of the second solution is the same as the solute of the first solution.

3. A process as claimed in claim 1 or claim 2, wherein the first solution contains more than one solute and the second solution contains a single solute.

4. A process as claimed in any one of the preceding claims, wherein water is removed from the first solution.

5. A process as claimed in any one of the preceding claims, wherein the second solution is of a known composition.

6. A process as claimed in any one of the preceding claims, wherein the second solution is a sodium chloride solution.

7. A process as claimed in any one of the preceding claims, wherein the second solution is substantially free of suspended particles.

8. A process as claimed in any one of the preceding claims, wherein the solvent of the second solution is the same as the solvent of the first solution.

9. A process as claimed in any one of the preceding claims, which is a continuous process.

10. A process as claimed in any one of the preceding claims, wherein solvent is extracted from the second solution by a method selected from the group consisting of distillation, ion exchange, electro-dialysis, and reverse osmosis.

11. A process as claimed in any one of the preceding claims, wherein the first solution is a waste stream from an industrial or agricultural process.

12. A process as claimed in any one of claims 1 to 10, wherein the first solution is a saline solution.

13. A process as claimed in claim 12, wherein the saline solution is seawater or brackish water.

14. Use of a direct osmosis step in the desalination of a saline solution by reverse osmosis.

15. Use as claimed in claim 14, wherein the saline solution is seawater or brackish water.

16. A process as herein described with reference to the accompanying drawings.

17. Use as herein described with reference to the accompanying drawings.

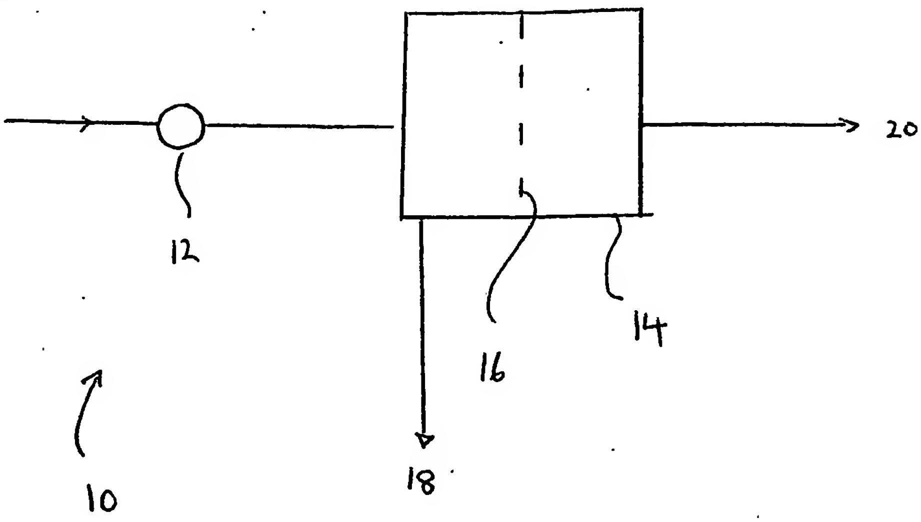

Figure 1

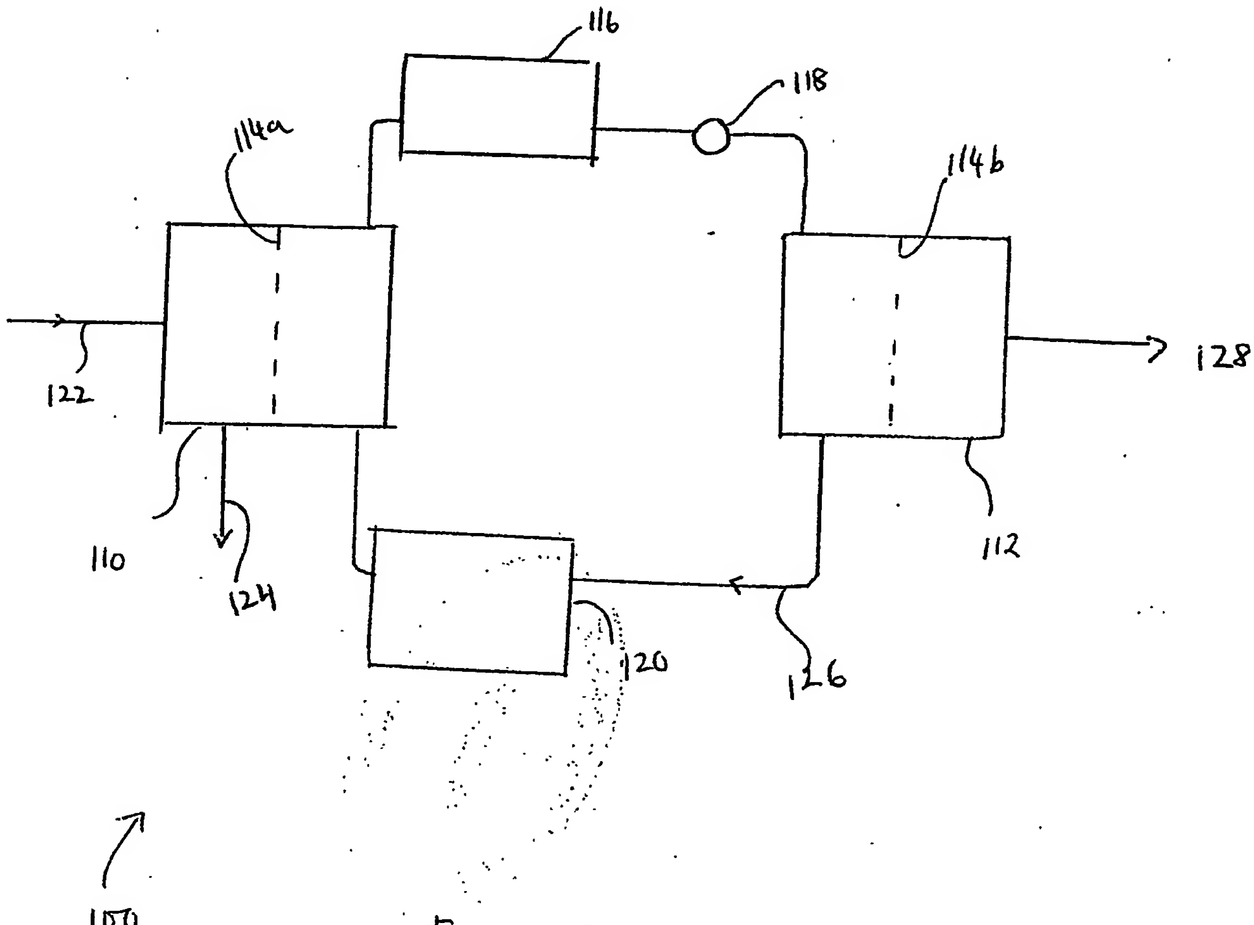

Figure 2

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